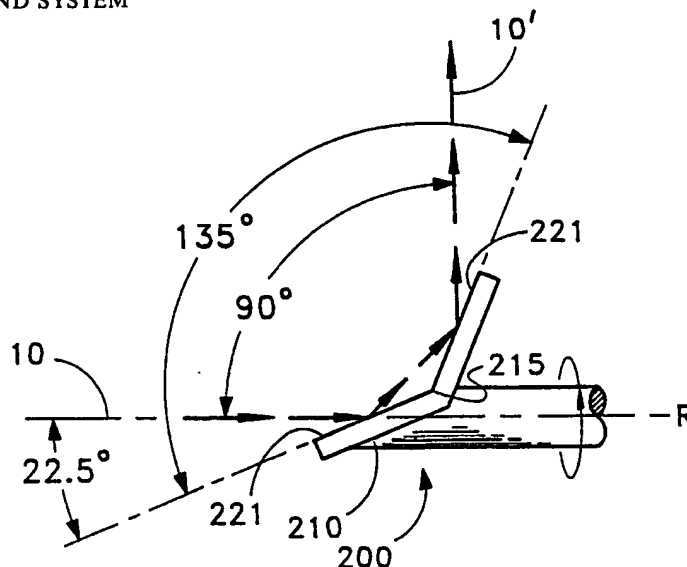




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(54) Title: LIGHT SCANNER AND SYSTEM



(57) Abstract

A light scanning system is disclosed which reduces the effects of wobble without the need for complex, cumbersome, or expensive optical equipment. A light source (110) is provided for generating an input light beam (10). A rotatable support is provided, and has an axis of rotation that is substantially parallel to the input light beam. A reflector subsystem (200) is provided, and includes one or more reflector pairs. Each of the reflector pairs is mounted on the support at a different azimuthal location around the axis of the rotatable support. Each of the reflector pairs has first (211) and second (221) light-reflective plane surfaces, the planes of which intersect at an obtuse angle. The first light-reflective surface (211) is oriented to receive the input light beam (10) during at least a portion of each rotational cycle of the rotatable support and to reflect said beam toward the second light-reflective surface (221), and the second light-reflective surface (221) is oriented to further reflect the light beam (10) to be approximately orthogonal the direction of the input light beam. The disclosed structure has a scan rate and duty cycle that depends on the number of reflector pairs used.

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Description

LIGHT SCANNER AND SYSTEM

FIELD OF THE INVENTION

This invention relates to light scanners, and, more particularly, to an improved light scanner and light scanning system with wobble correction and with improved scan rate and duty cycle.

BACKGROUND OF THE INVENTION

There are various important uses for light scanners which scan a collimated light beam, often a laser beam, in a line pattern across a target. This is commonly achieved by using a rotating optical scanner which repetitively scans the laser beam to produce a line scan. Among the applications for such scanners are copying and facsimile equipment, laser printers, character recognition equipment, and specialized graphics equipment. The accuracy of the scan is generally an important factor in equipment performance. Unfortunately, undesired angular perturbations in the cross-scan direction, called "wobble", result in a scanned line that varies from its intended straight or repetitive path. The wobble can be due to angular differences between multiple elements (e.g. facets) which form the repetitive scans, and/or due to pseudo-random angular shaft errors, often resulting from bearing non-uniformities. Even when the optical scanner is a single-facet device in which periodic differences may be nulled on a once-per-revolution basis, the residual pseudo-random errors can cause significant misplacements of the scan lines in the image area.

There have been various prior art approaches to reducing wobble. One method is the use of anamorphic (usually cylindrical) optics for wobble reduction. This is

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accomplished by first compressing the height of the illuminating beam incident upon the scanner in the cross-scan direction only (usually with an input cylinder) and then, after the beam is deflected, re-expanding the beam in the cross-scan direction only (usually with an output cylinder) as it propagates through the balance of the system optics, before forming the final focused image. Cross-scan angular error is reduced by the ratio of the beam compression (or re-expansion). For further description, reference can be made to the book by L. Beiser, "Holographic Scanning", John Wiley, (1988). However, in the case of the single facet scanner whose mirror is mounted at 45° to the rotating axis while the input beam is paraxial, this correction method fails because the compressed component of illumination is intercepted at different angles as the facet rotates, distorting and skewing its output during scan.

Another technique of wobble reduction utilizes a single linear (transmission) holographic grating mounted to a shaft at 45° such that it acts as a 45° mirror. It reduces cross-scan errors when the input and output beams are related to the grating normal by the Bragg angle (in this case, 45°). In addition to the specialized technology necessary for making such gratings, the angular sensitivity of the gratings at different wavelengths, and the diffraction efficiency sensitivity to different polarization angles during rotation are limiting factors.

U.S. Patent No.s 4,475,787 and 4,606,601 disclose methods and apparatus for reducing wobble using double reflection. U.S. Patent 4,475,787 shows a pentaprism or pentamirror mounted to the rotating shaft to act as a monogon (single facet scanner). Double-reflection nulls the cross-scan error; that is, the error of the first reflection is nulled by an equal and opposite second reflection. Limitations of this approach are the significant bulk and unbalanced mass of the penta components, requiring further

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counter-balancing to achieve stable rotation. Also, the components form a relatively large optical assembly which can impose packaging and cost constraints. A variation described in U.S. patent 4,606,601 operates also by double reflection; however, only as a right angle roof mirror or prism upon an input beam which is incident normal to the axis.

It is among the objects of this invention to provide a light scanner which reduces wobble, but without the limitations or drawbacks of prior art wobble correction schemes.

SUMMARY OF THE INVENTION

The present invention is directed to a light scanner and a light scanning system which reduces the effect of wobble without the need for complex, cumbersome, or expensive equipment. In accordance with an embodiment of the light scanning system, a light source is provided for generating an input light beam. A reflector subsystem receives the input light beam, the subsystem including first and second light-reflective plane surfaces, the planes of which intersect at an obtuse angle. The first light-reflective surface is oriented to receive the input light beam and reflect it toward the second light-reflective surface, and the second light-reflective surface is oriented to further reflect the light beam to be approximately orthogonal the direction of said input light beam. Means are provided for rotating the reflector subsystem on an axis which substantially corresponds to the direction of the input light beam.

In a preferred embodiment of the invention, the planes of said first and second light-reflective surfaces intersect to include an angle of about 135° . In this embodiment, the axis of rotation of the reflector subsystem forms an angle of about 22.5° with respect to said first light-reflective surface.

In a form of the invention, the light beam reflected from the second light-reflective surface is called the reflector subsystem output beam, and means are provided for focusing said reflector subsystem output beam. The focusing means includes a lens which is operative to focus substantially parallel displaced beams to a single scan line upon rotation of the reflector subsystem.

In accordance with a further embodiment of the invention, a rotatable support is provided, and has an axis of rotation that is substantially parallel to the input light beam. A reflector subsystem is provided, and includes

a plurality of reflector pairs. Each of the reflector pairs is mounted on the support at a different azimuthal location around the axis of the rotatable support. Each of the reflector pairs has first and second light-reflective plane surfaces, the planes of which intersect at an obtuse angle. The first light-reflective surface is oriented to receive the input light beam during at least a portion of each rotational cycle of the rotatable support and to reflect said beam toward the second light-reflective surface, and the second light-reflective surface is oriented to further reflect the light beam to be approximately orthogonal the direction of the input light beam. In a preferred form of the further embodiment of the invention, for each reflector pair, the line defined by the intersection of the light-reflective plane surface of said pair is designated as an intersection line, and the intersection lines of all reflector pairs are in substantially the same plane; i.e., a plane substantially perpendicular to the rotational axis of the rotatable support.

The further embodiment of the invention has the advantage of multiplying the scan rate and duty cycle by the number of reflector pairs used. For example, if two reflector pairs are utilized, there will be two scans (one implemented by each reflector pair) per complete revolution of the rotatable support. If four reflector pairs are utilized, there will be four scans per complete revolution of the rotatable support.

Further features and advantages of the invention will become more readily apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram, partially in block form, of a light scanning system in accordance with an embodiment of the invention.

Fig. 2 shows the reflector subsystem of the Fig. 1 system, and illustrates operation thereof.

Fig. 3 is a top view of the reflector subsystem of Fig. 2.

Fig. 4 is a front view of the reflector subsystem of Fig. 2.

Fig. 5 is a diagram which illustrates the wobble correcting operation of the light scanning system of the invention hereof.

Fig. 6 is a side view of an embodiment of the invention which utilizes two reflector pairs.

Fig. 7 is a front view of the Fig. 6 embodiment.

Fig. 8 is a top view of the Fig. 6 embodiment.

Fig. 9 is a side view of another embodiment of the invention which utilizes four reflector pairs.

Fig. 10 is a front view of the Fig. 9 embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 1, there is shown a schematic diagram, partially in block form, of a light scanner system in accordance with an embodiment of the invention. A laser 110, which may have associated optics (not separately shown), produces a coherent light beam 10 that is input to an optical scanner subsystem 200. The beam 10 is preferably, although not necessarily, collimated and coherent. The term "light" is intended to generically include visible and near-visible light as well as other radiation having similar optical properties and which can be scanned with moveable optical elements.

The reflector subsystem, which is illustrated in further detail in Figs 2, 3 and 4, includes two plane mirrors, 211 and 221 which are mounted on a base 210 and meet at a vertex 215 to form a nominal included angle of 135° . As seen in Fig. 2, mirror 211 is oriented at an angle of 22.5° with respect to the axis of rotation (dashed line R of the reflector subsystem). A motor 250 is utilized to rotate the reflector subsystem on the axis R. The input beam is substantially the same direction as the rotation axis R, and in the embodiment of Figs 1-4 it is co-linear with the rotation axis R. As seen in Figs 1 and 2, for example, the input beam 10 reflects off mirror 211 toward mirror 221, and then reflects off mirror 221. The beam exiting the reflector subsystem is called the reflector subsystem output beam and is designated 10'. The reflector subsystem output beam 10' is seen to exit at an angle of 90° from the axis R. Because of the double reflection and the 135° nominal included angle, the exiting beam is stabilized at this angle of 90° from the axis, independent of small variations in the orientation of the mirror pair with respect to the rotation axis (i.e. variation in the 22.5° angle). Thus, the 22.5° typical angle may be set at any convenient angle, and upon varying dynamically by any

erroneous angle (e.g. during scanning rotation about the axis), that output beam 10' will remain directed 90° from the input beam.

In the embodiment of Fig. 1, the output beam 10' passes through focusing lens 140 and impinges on target 170. The target 170 may be, for example, a drum having its axis perpendicular to the plane of the paper. In operation of the light scanning system of Fig. 1, as the reflector subsystem is rotated, the output beam 10' will scan lines on the target in the plane perpendicular to the plane of the paper. [The beam will actually continue to scan, after leaving the target, and make a full 360° scan for each revolution of the reflector subsystem. Only a portion of each scan revolution may impinge on the target.]

Fig. 5 illustrates the wobble correction that results from the double reflection hereof. The solid line mirrors and solid line beam represents the no-wobble situation. The broken line version of the mirror shows the mirror position for an example of wobble error, and the dashed line beam shows the beam path for the wobble situation. As seen in the diagram, the first reflection (from mirror 211) results in twice the angular change of the mirrors due to the wobble. Upon reflection from the second mirror (215, with the wobble error) the original output direction is restored, and it is seen that the beam with wobble (dashed line) is parallel to the beam without wobble. The lens 140 can then operate to focus the beam to its originally desired position, as illustrated by the exaggerated dotted line 11 in Fig. 1. The concept of correction with double reflection was known in the art, but it achieves this double reflection with a structure that is simpler, less cumbersome, better balanced, and less expensive than previous structures.

Referring to Figs 6-8, there is shown an embodiment of the invention which utilizes two reflector pairs of the type

previously described, and which are arranged at different azimuthal locations around the rotational axis R of a rotatable support or shaft 620. In this embodiment, a first reflector pair 630 and a second reflector pair 650 are at respective 180 degree angular positions around the rotational axis R. The reflector pair 630 includes two plane mirrors 631 and 632 which meet at a vertex L_1 to form a nominal included angle of 135° . The reflector pair 650 includes two plane mirrors 651 and 652 which meet at a vertex L_2 to form a nominal included angle of 135° . The reflector pairs are mounted, by any suitable means, on shaft 620, which may be driven by a motor such as 250 of Fig. 1. It is seen that the scanner of Figs 6-8 provides two scans per revolution of the shaft 620 rather than one, as in the structure of Figs 1-4. Thus, for example, when a lens 140 and target 170 are provided as in Fig. 1, two scanlines on the target will be traversed for each revolution of shaft 620.

In the embodiment of Figs 9 and 10, four reflector pairs, 910, 920, 930 and 940 are illustrated as being located at 90° azimuthal spacings on the axis of rotatable support or shaft 905. The reflector pair 910 includes plane mirrors 911 and 912, the reflector pair 920 includes plane mirrors 921 and 922, the reflector pair 930 includes plane mirrors 931 and 932, and the reflector pair 940 includes plane mirrors 941 and 942. Again, the mirrors of each reflector pair meet at a vertex to form a nominal included angle of 135° . The vertices are designated L_1 , L_2 , L_3 and L_4 . The mirrors 912, 922, 932 and 942 are seen to have triangular shapes. The scanner of Figs 9 and 10 is seen to provide four scans per revolution of the shaft 905. Other numbers of reflector pairs can be utilized, for example three reflector pairs or more than four reflector pairs. As the number of reflector pairs is increased, the scan rate and duty cycle will increase, but at the expense of increased diameter of the scanner assembly (to provide a

sufficiently large optical aperture in the central triangular mirrors - e.g. as in Fig. 9) and the need for maintaining relative accuracy for a larger number of parameters. As in the embodiment of Figs 1-4, the rotation axis of the rotatable support member is in substantially the same direction as the input light beam (i.e., they are substantially co-linear or substantially parallel). In the embodiments of Figs 6-10, and as seen in Figs 6 and 9, the central ray of the input light beam is offset from the rotation axis. In this manner, as the shaft rotates (see e.g. Fig. 7) the beam impinges on successive reflector pairs to effect the successive scans. However, if desired, the central ray could be co-linear with the rotation axis, with a portion of the beam impinging on two or more reflector pairs, which would result in a plurality of scanned beams, one or more of which can be utilized. It will be understood that in such configuration any light not used will be wasted.

The accuracy requirements for multiple scanners entail two principal factors: equality of included angles (see e.g. α_1 and α_2 of Fig. 6); and parallelism of intersecting lines L (in a plane substantially perpendicular to the rotational axis). As shown above (see Fig. 5), the output angle is essentially independent of the angular orientation of the assembly. Thus, when $\alpha_1 = \alpha_2$ the output beams will superimpose on successive scans. The accuracy to which they overlap is determined (by mirror reflection) by twice the difference between the two angles. If, for example, $\alpha_1 - \alpha_2 = 1$ arc sec., then the output beams will superimpose within 2 arc sec.

The criterion for angular accuracy of L (e.g. L_1 and L_2 of Fig. 6) is derived from the law of double-reflection (see, for example, L. Levi, Applied Optics, Vol. 1, John Wiley & Sons, p. 348, 1968). In Fig. 6, for example, the component of the input beam which is perpendicular to L will

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be rotated by 2α with L as an axis; the component parallel to L will remain parallel to itself. Thus, if the perpendicular to line L is skewed to the input beam by a small angle x , the rotated component will be twice the cosine of the skew angle and the error will be twice the residue, or $2(\cos 0 - \cos x) = 2(1 - \cos x)$. Since, for small angles, $\cos x = 1 - x^2/2$, the error component ϵ is $\epsilon = 2(x^2/2) = x^2$; that is, equal to the square of the angular deviation. Conversely, the allowed deviation from parallelism of the line L to the rotating axis is $x = \sqrt{\epsilon}$.

The invention has been described with reference to particular preferred embodiments, but variations within the spirit and scope of the invention will occur to those skilled in the art. For example, it will be understood that further optical elements can be employed that are either attached to or separate from the rotating reflective subsystem. In this regard, a lens could be mounted in conjunction with the reflective subsystem to focus the exiting beam in desired fashion. Further, if it is desired to have the scan at an angle other than 90° with respect to the input beam, the angle between the reflective surfaces can be varied from the nominal 135° angle.

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CLAIMS:

1. A light scanner for scanning an input light beam and which reduces the effects of wobble on cross-scan scanning error, comprising:

a reflector subsystem including first and second light-reflective plane surfaces, the planes of which intersect at an obtuse angle, said first light-reflective surface being oriented to receive said input light beam and reflect said beam toward said second light-reflective surface, and said second light-reflective surface being oriented to further reflect said light beam to be approximately orthogonal the direction of said input light beam; and

means for rotating said reflector subsystem on an axis which substantially corresponds to the direction of the input light beam.

2. The light scanner as defined by claim 1, wherein the planes of said first and second light-reflective surfaces intersect to include an angle of about 135°.

3. The light scanner as defined by claim 1 or 2, wherein said axis of rotation forms an angle of about 22.5° with respect to said first light-reflective surface.

4. The light scanner as defined by claim 1, wherein said means for rotating said reflector subsystem comprises a motor.

5. The light scanner as defined by claim 1, 2, 3 or 4, wherein said means for rotating includes a rotatable support having an axis of rotation that is substantially parallel to said input light beam; and wherein said reflector subsystem includes a plurality of reflector pairs of said first and second light-reflective plane surfaces,

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each of said reflector pairs being mounted on said support at a different azimuthal location around the axis of said rotatable support; said reflector pairs being arranged to receive said input light beam during at least a portion of each rotational cycle of the rotatable support.

6. The light scanner as defined by claim 5, wherein the central ray of said input light beam is offset from the rotational axis of said rotatable support.

7. The light scanner as defined by claim 5 or 6, wherein said plurality of reflector pairs comprises two reflector pairs.

8. The light scanner as defined by claim 5 or 6, wherein said plurality of reflector pairs comprises four reflector pairs.

9. The light scanner as defined by claim 5, wherein, for each reflector pair, the line defined by the intersection of the light-reflective plane surfaces of said pair is designated as an intersection line, and wherein the intersection lines of all the reflector pairs are in substantially the same plane.

10. The light scanner as defined by claim 9, wherein said same plane is substantially perpendicular to the rotational axis of said rotatable support.

11. A light scanning system, comprising:
a light source for generating an input light beam;
a reflector subsystem for receiving said input light beam and including first and second light-reflective plane surfaces, the planes of which intersect at an obtuse angle, said first light-reflective surface being oriented to

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receive said input light beam and reflect said beam toward said second light-reflective surface, and said second light-reflective surface being oriented to further reflect said light beam to be approximately orthogonal the direction of said input light beam; and

means for rotating said reflector subsystem on an axis which substantially corresponds to the direction of the input light beam.

12. The light scanning system as defined by claim 11, wherein the light beam reflected from the second light-reflective surface is the reflector subsystem output beam, and further comprising focusing means for focusing said reflector subsystem output beam.

13. The light scanning system as defined by claim 12, wherein said focusing means includes a lens which is operative to focus substantially parallel displaced beams to a single scan line upon rotation of the reflector subsystem.

14. The light scanning system as defined by claim 11, 12 or 13, wherein the planes of said first and second light-reflective surfaces intersect to include an angle of about 135°.

15. The light scanning system as defined by claim 11, 12 or 13, wherein said axis of rotation forms an angle of about 22.5° with respect to said first light-reflective surface.

16. The light scanning system as defined by claim 11 or 12, wherein said means for rotating said reflector subsystem comprises a motor.

17. The light scanning system as defined by any of claims 11-16, wherein said means for rotating includes a

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rotatable support having an axis of rotation that is substantially parallel to said input light beam; and wherein said reflector subsystem includes a plurality of reflector pairs of said first and second light-reflective plane surfaces, each of said reflector pairs being mounted on said support at a different azimuthal location around the axis of said rotatable support; said reflector pairs being arranged to receive said input light beam during at least a portion of each rotational cycle of the rotatable support.

18. The light scanning system as defined by claim 17, wherein the axis of said input light beam is offset from the rotational axis of said rotatable support.

19. The light scanning system as defined by claim 17 or 18, wherein, for each reflector pair, the line defined by the intersection of the light-reflective plane surfaces of said pair is designated as an intersection line, and wherein the intersection lines of all the reflector pairs are in substantially the same plane.

20. The light scanning system as defined by claim 19, wherein said same plane is substantially perpendicular to the rotational axis of said rotatable support.

21. A light scanner for scanning an input light beam, comprising:

- a rotatable support having an axis of rotation;
- a reflector subsystem including a plurality of reflector pairs, each of said reflector pairs being mounted on said support at a different azimuthal location around the axis of said rotatable support;

- each of said reflector pairs having first and second light-reflective plane surfaces, the planes of which intersect at an obtuse angle, said first light-reflective

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surface being oriented to receive said input light beam during at least a portion of each rotational cycle of the rotatable support and to reflect said beam toward said second light-reflective surface, and said second light-reflective surface being oriented to further reflect said beam to be approximately orthogonal the direction of said axis of rotation.

22. The light scanner as defined by claim 21, further comprising means for rotating said rotatable support on its axis.

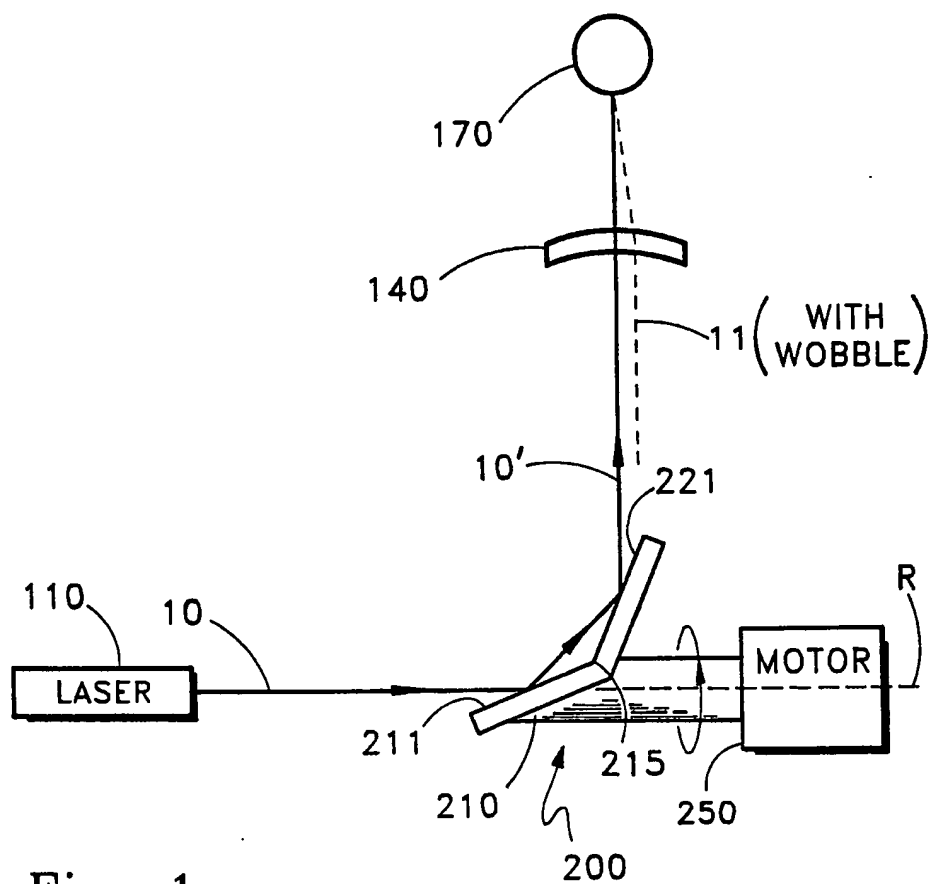


Fig. 1

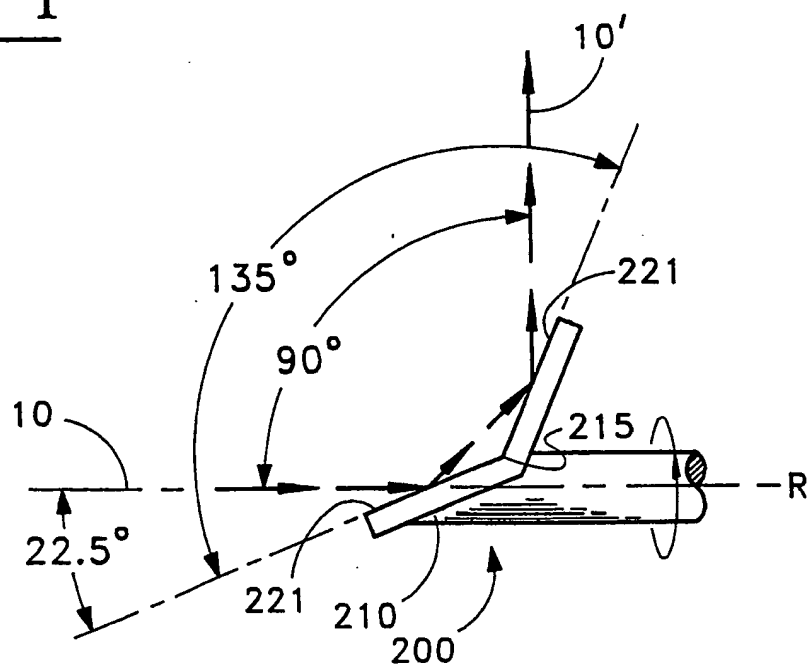


Fig. 2

Fig. 3

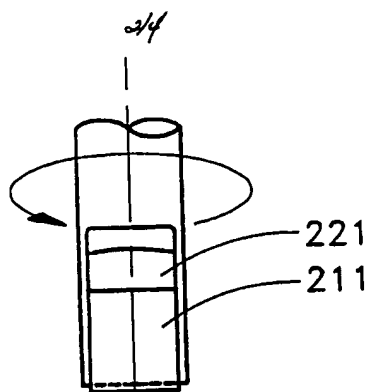


Fig. 4

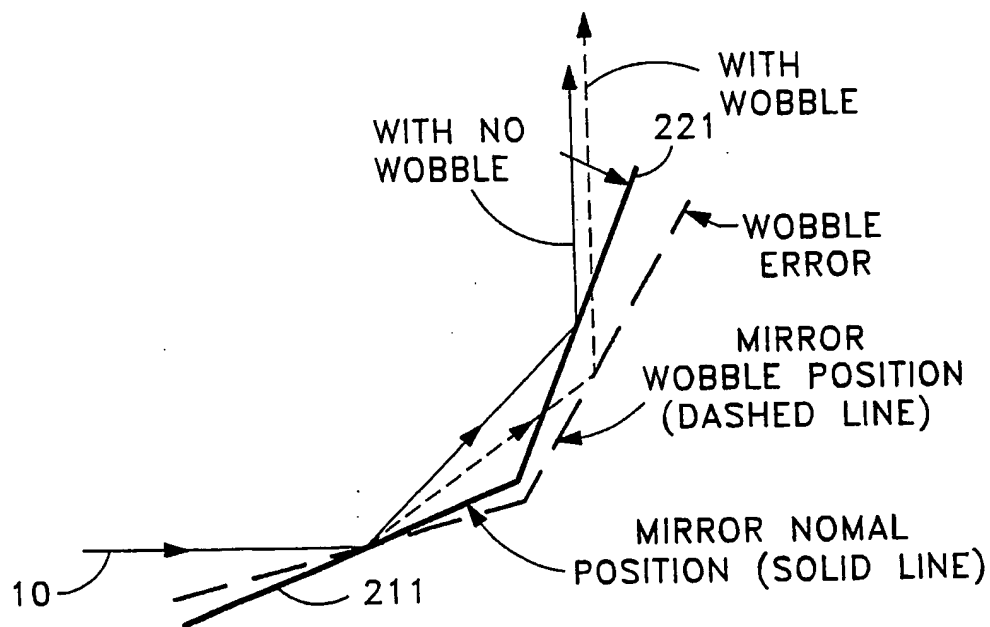
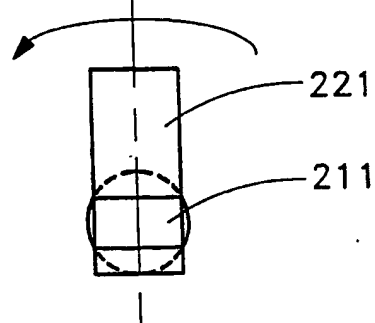


Fig. 5

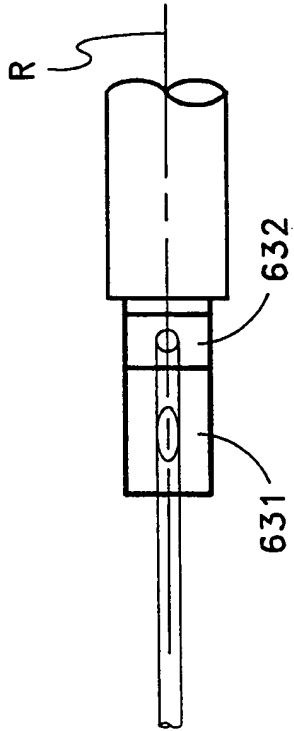


Fig. 8

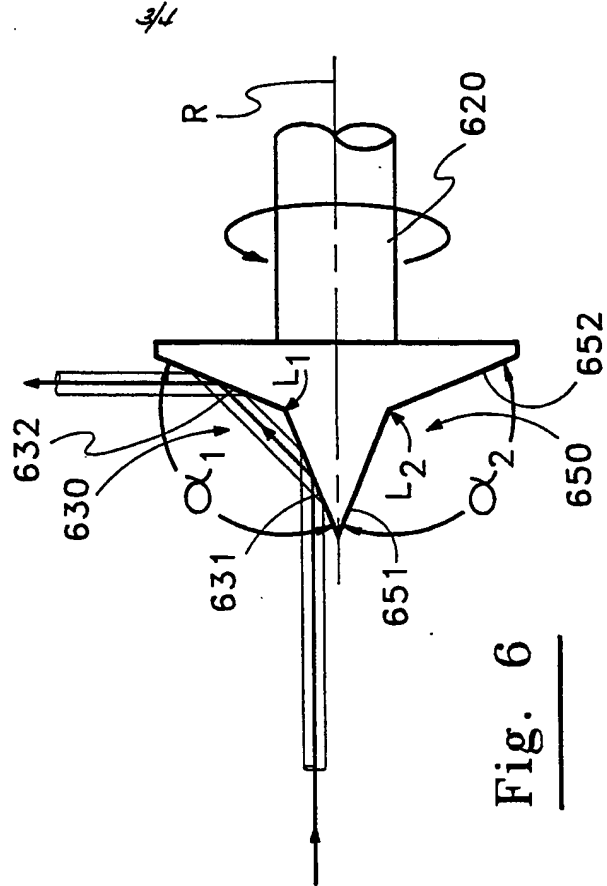


Fig. 6

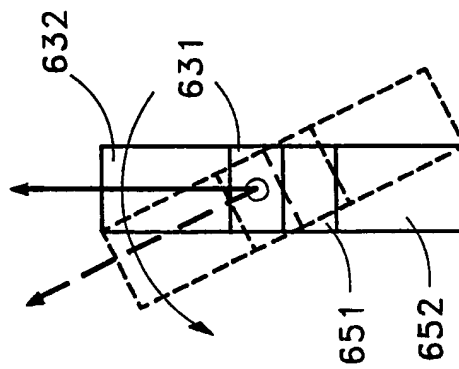


Fig. 7

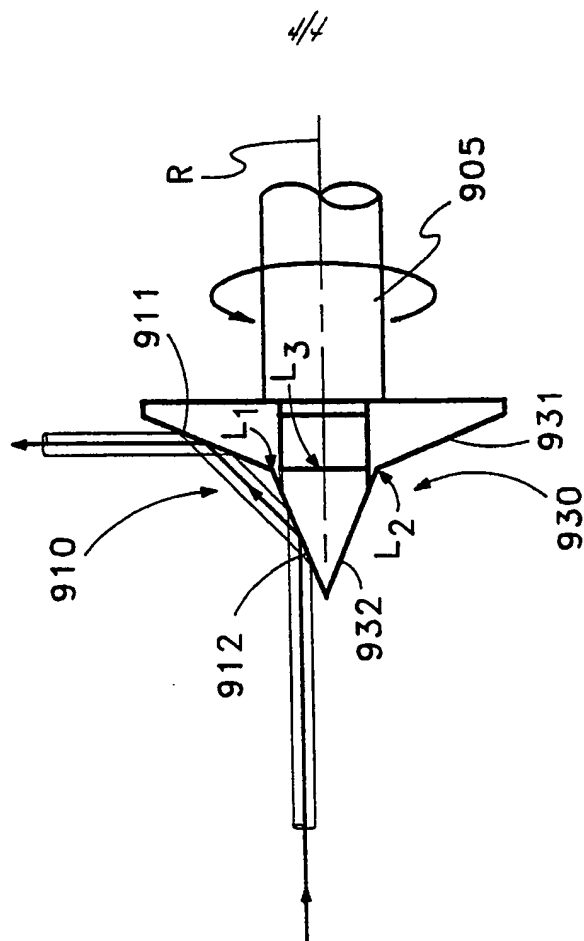


Fig. 9

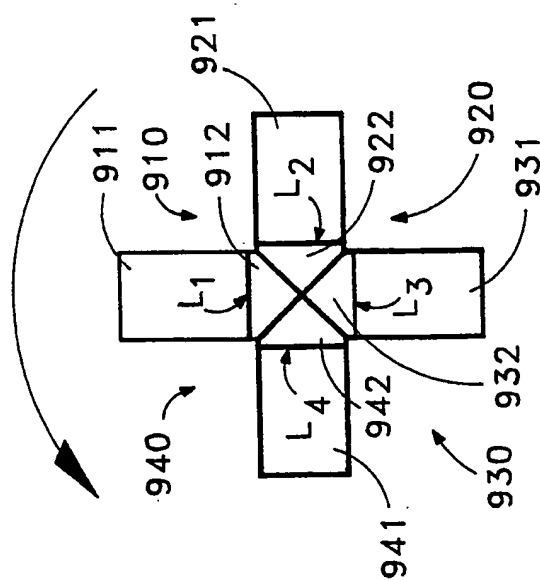


Fig. 10

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/03285

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC		
INT. CL. 5 G02B 26/10 U.S. CL. 350/6.5		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S.	350/6.5	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category [*]	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
A	US, A, 4,796,965, (ISHIKAWA) 10 JANUARY 1989 Column 2, lines 56-65	1-22
<p>[*] Special categories of cited documents: ¹³</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the International filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"Δ" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²		Date of Mailing of this International Search Report ³
12 SEPTEMBER 1990		07 NOV 1990
International Searching Authority ¹		Signature of Authorized Officer ²⁰
ISA/US		<i>Bruce Y. Arnold</i> BRUCE Y. ARNOLD